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Summary

It has been speculated that the episodes of ozone sickness experienced by some airline passengers and crew members during the winter and spring of 1977 were induced by abnormally high concentrations of ambient atmospheric ozone. To investigate the possibility that 1976–77 was anomalous, ozone measurements from balloons for up to 13 years and from Global Atmospheric Sampling Program (GASP) equipped aircraft for three years have been studied. The analyses presented herein show that the winter and spring seasons of 1976–77 were average statistically, and no evidence was found to suggest that there was more than a usual variation in the frequency that commercial airplanes encountered high ambient ozone concentrations.

Introduction

Ozone in the atmosphere is at least as variable, in all three spatial dimensions and in time, as most other constituents or indicators of the atmospheric circulation. On the average, ozone levels (mixing ratios expressed in parts per million by volume) are relatively small and constant with altitude through the troposphere, but they increase rapidly with altitude above the tropopause (refs. 1 and 2). Thus the mean ozone level encountered on any given route is influenced by the frequency and extent of penetration into the stratosphere. Because the tropopause slopes gently downward toward the pole and has lowest mean heights during winter and spring and because lower stratospheric ozone levels are greatest in the spring (ref. 3), it follows that, at any given flight level, ozone amounts are greatest in the spring at middle and high latitudes. However, since stratospheric ozone amounts vary greatly about their mean values and are highly influenced by weather systems (refs. 2 and 4), very large values can be found at other locations during other seasons also.

Ozone is a relatively unstable gas, but apparently partly survives compression. A brief measurements campaign in the early 1960's established that the ozone ingested by aircraft operating in the stratosphere is only partially destroyed by the aircraft's compression-ventilation system (ref. 5). This was later confirmed by measurements made by the NASA Global Atmospheric Sampling Program (GASP) which also showed that considerable variation in the fraction of ozone destroyed could be expected based on the aircraft ventilation system configuration (ref. 6).

Although ozone has always been present in the stratosphere, during 1977 airliner cabin ozone levels became a matter of widespread public concern (refs. 7 to 10). Was this concern the result of new aircraft design (ref. 8), higher flight altitudes (ref. 8), increased public awareness (one account describes ozone sickness as a "new" danger (ref. 10)), or was the winter of 1977 an anomalous period with respect to ozone as suggested in references 7, 8, and 11? That reports came initially and most frequently from B747SP airplanes is not surprising in view of recent analyses of cabin and ambient ozone data from a GASP-equipped SP which showed that 83 percent of the outside ozone was admitted into the cabin (refs. 12 to 14)[1]. In addition, the analyses in reference 6 showed that the GASP-equipped B747SP was encountering high ambient ozone much more frequently than any of the other GASP-equipped airliners. The authors attributed the difference to the higher altitudes typical of SP flights as well as to the greater frequency of flights at high latitudes.

The purpose of this report is to investigate, from an observational point of view by using all available ozone measurements made from airplanes or balloons, the possibility that anomalous weather conditions contributed to the problem. Specifically, two questions will be addressed in this study:

1. Were atmospheric ozone levels higher than normal during the ozone season (December–May) of 1976–77?
2. Were high ozone levels encountered more frequently than normal during this time period?

Results and Discussion

Mean Value Statistics

Ozonesondes.—Because of their relatively long period of record, balloon ozone data are useful for deciding if the atmospheric ozone levels at airliner

[1]Subsequent air conditioning modifications, including a filter installation, reduced this value to less than 8 percent. For comparison, note that the retention ratio for a B747-100 was found to be 47 percent (refs. 12 to 14).

Figure 1. - Distribution of Northern Hemisphere GASP routes and ozonesonde stations used in present analysis.

cruise altitudes were higher than normal during the 1977 ozone season (the term ozone season will be used to indicate the period December through May and is divided into the calendar seasons of winter, December–February, and spring, March–May). Balloon soundings of atmospheric ozone (ozonesondes) have been carried out at many stations in the past (ref. 3), but for this study only stations with data into 1977 were used. The stations thus suited for use here are shown in figure 1 and listed in table I. These stations each averaged about five observations per month; at least one study (ref. 11) has shown that five observations are enough to give representative mean values. Unfortunately, the ozonesonde stations over Japan averaged less than six observations per year during 1976 and 1977 and could not be included here. Ozonesonde data used were obtained from the World Data Center for Ozone in Toronto, Canada.

Mean ozone mixing ratios during winter and spring at 200 and 150 hectopascals (hPa), near flight levels 390 and 450 (39 000 and 45 000 ft), respectively, for three stations are given in figure 2. The three stations are located near 50° N latitude and are spaced in longitude between 15° E and 115° W (see fig. 1). The solid line through each curve in figure 2 is the long term station-mean mixing ratio and, for easy reference, error bars extending one standard error of the mean on either side of the mean have been placed on the line at 1977. In no case for the stations in figure 2 can the ozone be called abnormally high during 1977, in fact, only the winter values at Berlin and the 200-hPa spring value at Goose are above the long term means.

TABLE I. - OZONESONDE STATIONS

Station	Latitude	Longitude	Years of data
Resolute	74.7° N	95.0° W	1966-78
Churchill	58.8° N	97.1° W	1973-78
Edmonton	53.6° N	114.1° W	1972-78
Goose	53.3° N	60.1° W	1969-78
Berlin/Lindenberg	52.5° N	13.4° E	1966-72, 1975-78
Hohenpeissenberg	47.8° N	11.0° E	1965-75, 1977-78
Payerne	46.8° N	6.9° E	1968-Jan. 1977
Wallops	37.9° N	75.5° W	1970-78

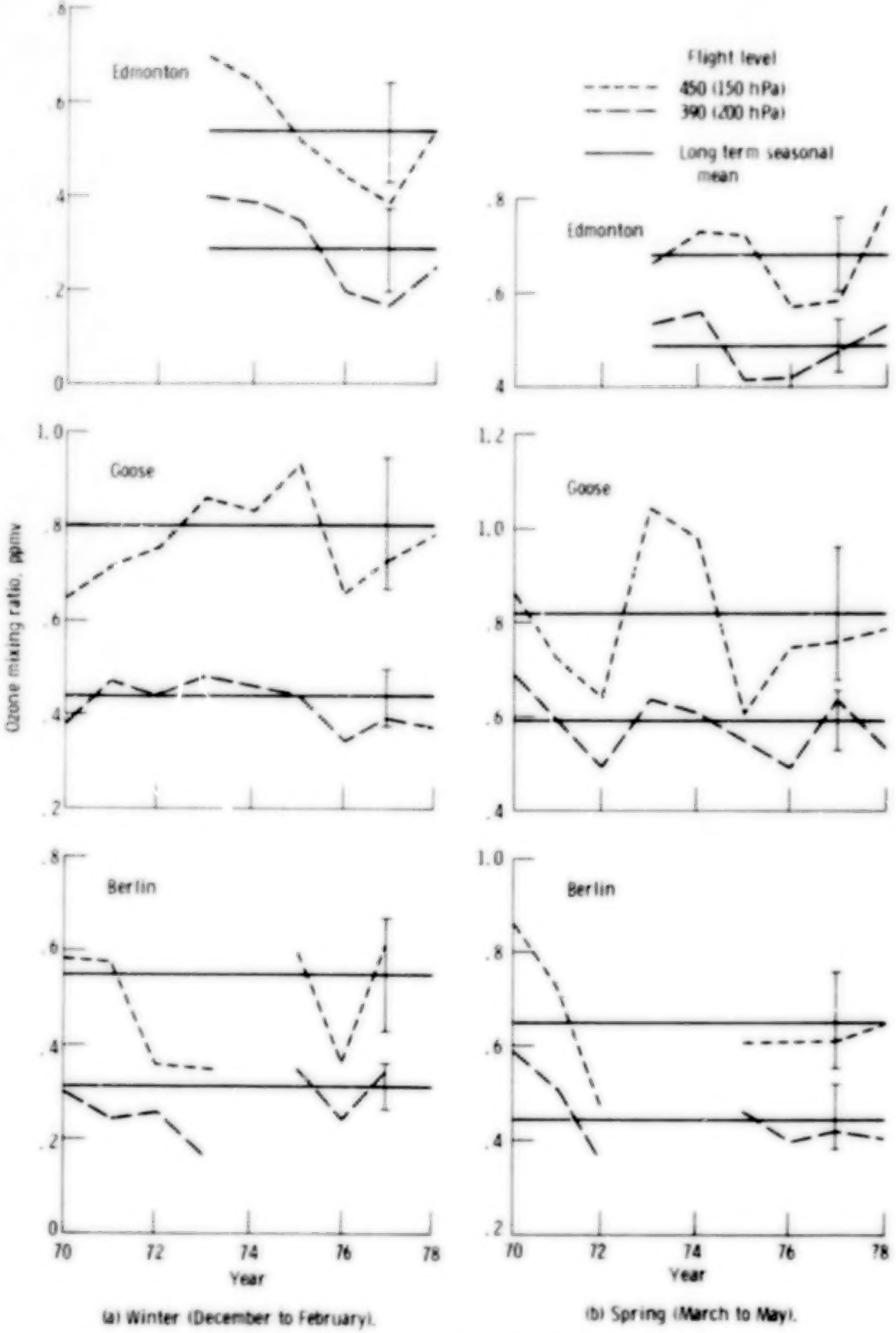


Figure 2. - Time series of seasonal mean values of zone mixing ratios at ozonesonde stations near 50° N. Errors bars extend one standard deviation above and below the long term mean.

A summary of the ozonesonde data at all eight stations is given in table II. The final column of this table gives the difference between the 1977 mean and the long term mean, divided by the standard deviation of the long term mean, to help normalize the values among the stations. For data with a normal (bell-shaped) distribution, this ratio can be expected to exceed 1.3 about 1 out of 10 times (once per decade) and to exceed 2.0 in 1 out of 50 times (twice per century). Only the 150-hPa winter value at Hohenpeissenberg is a 1 in 10 value, and no value approaches the 1 in 50 limit. Note also that the

TABLE II. - COMPARISONS OF SEASONAL MEAN OZONE FROM OZONESONDES FOR ALL YEARS OF RECORD WITH THE SEASONAL MEANS DURING WINTER AND SPRING OF 1976-77

Station	Season	Level (hPa)	Mean, ppmv	Standard deviation, σ, ppmv	Number of years data were taken	Mean for 1976-77, ppmv	Number of observations for 1976-77	$\frac{(1976\text{-}77) - \text{mean}}{\sigma}$
Resolute	Winter	150	1.014	0.199	13	1.051	11	0.2
		200	.511	.082	13	.530	11	.2
	Spring	150	1.075	.145	13	1.049	12	-.2
		200	.731	.105	13	.817	12	.8
Churchill	Winter	150	.687	.067	5	.657	14	-.4
		200	.356	.057	5	.378	14	.4
	Spring	150	.832	.147	5	.862	7	.2
		200	.580	.061	5	.556	7	-.4
Edmonton (see fig. 1)	Winter	150	.538	.110	6	.386	13	-1.4
		200	.292	.092	6	.169	13	-1.3
	Spring	150	.671	.081	6	.576	12	-1.2
		200	.482	[illegible]	6	.470	12	-.2
Goose (see fig. 1)	Winter	150	.797	.136	10	.726	14	-.5
		200	.431	.061	10	.394	14	-.6
	Spring	150	.805	.146	10	.753	12	-.4
		200	.577	.063	10	.627	12	.8
Berlin (see fig. 1)	Winter	150	.553	.116	10	.620	14	.6
		200	.315	.048	10	.345	14	.6
	Spring	150	.664	.111	10	.598	12	-.6
		200	.456	.069	10	.428	12	-.4
Hohen-peissenberg	Winter	150	.593	.094	13	.653	9	1.6
		200	.266	.065	13	.332	9	1.0
	Spring	150	.654	.188	12	.480	13	-.9
		200	.412	.177	12	.217	13	-1.7
Payerne	Winter	150	.434	.080	9	.429	22	-.1
		200	.220	.036	9	.230	24	.0
	Spring	150	.569	.102	8	M	0	M
		200	.381	.055	8	M	0	M
Wallops	Winter	150	.371	.045	5	.428	11	1.2
		200	.218	.083	5	.281	11	.8
	Spring	150	.408	.069	5	.455	13	.7
		200	.282	.012	5	.255	13	-1.4

1976–77 value was less than the long term means at slightly over half of the stations and levels compared. Thus, both inspection of the data and statistical tests show that, at ozonesonde stations from 35° to 75° N latitude and 15° E to 115° W longitude, the ozone levels at airliner cruise altitudes were not abnormally high during the 1977 ozone season.

Seasonally averaged data, as used above, give a coarse picture and may conceal features that would be evident if a finer time interval were used for averaging. In particular, there was a major stratospheric sudden warming (refs. 15 to 17) during late December 1976 and early January 1977, which disrupted the atmospheric circulation patterns throughout the stratosphere and troposphere. Although the disturbed circulation may have affected ozone at higher altitudes or at other locations, it did not significantly raise the ozone levels during January 1977 at the three stations near 50° N shown in figure 3. Similarly, the monthly mean data at the other five available stations gave no indication that ozone levels were abnormally high during January 1977. Thus we find, from direct analysis of ozonesonde data, no evidence to suggest that abnormally high ozone levels were present in the 1976–77 ozone season, either seasonally or in conjunction with the stratospheric warming. This conclusion is contrary to the suggestion (ref. 11) that a long period oscillation caused high ozone levels in 1977.

The preceding results cannot be directly generalized to areas where there are no ozonesonde stations. However, since the heights of pressure levels near the tropopause are known to be highly correlated with the ozone amounts at those levels (ref. 4), height data may be used as an indicator of ozone in areas where ozone was not directly measured. In particular, at say 60° N, 180° W (along the North Pacific flight route where many of the cases of discomfort attributed to ozone were reported), the deviations of the monthly mean 300 hPa heights from a 10 year mean (ref. 18) were no larger than the corresponding height deviations at the ozonesonde stations. This comparison suggests that ozone levels over the North Pacific were probably no more anomalous than those given in table II. Of course, direct measurements are always more desirable than proxy data such as height fields, and, even though they span only a few years, the GASP ozone data presented in the following sections fully support the above conclusion.

GASP Aircraft Measurements.—Another set of ambient ozone data which is directly relevant to this study was acquired by the NASA Global Atmospheric Sampling Program beginning in March 1975 using automated sampling systems on several Boeing 747 airliners in routine commercial service (ref. 19). GASP ozone data were shown in reference 2 to be in excellent agreement with comparable ozonesonde data. We shall consider here over 20 000 GASP observations in the Northern Hemisphere spanning three spring seasons (Mar–May 1975, 1976,

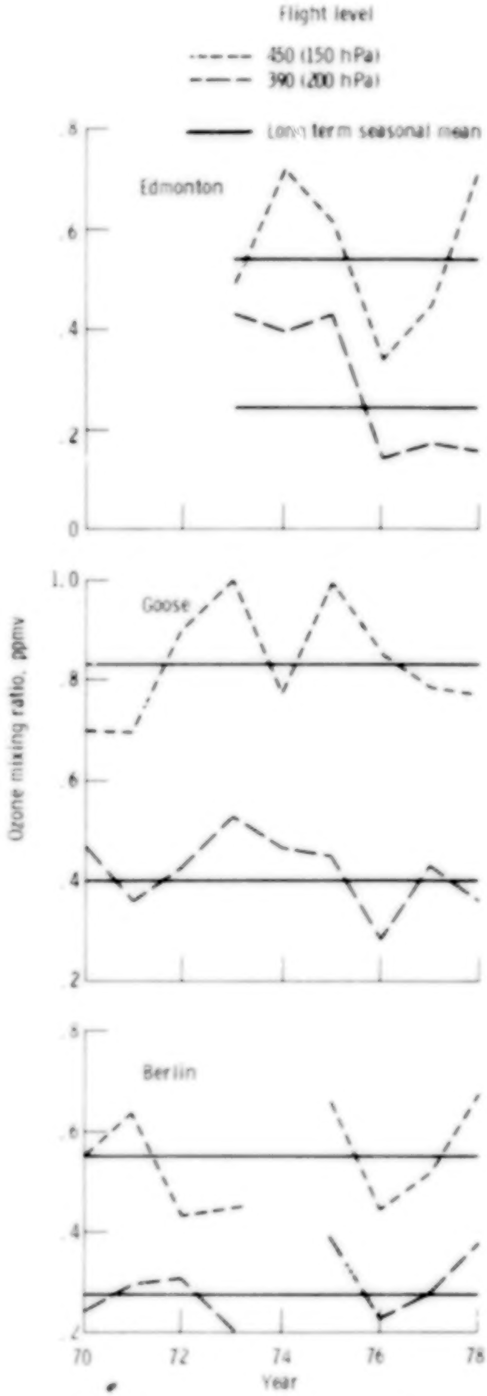


Figure 3. - Time series of January mean values of ozone mixing ratio at ozonesonde stations near 50° N.

TABLE III. - INTERANNUAL COMPARISON OF GASP MEAN OZONE DATA AT

FLIGHT LEVELS 335 TO 385

(a) Winter

Code[a]:

Mean	Std. dev.	# Obs.
Median	84%	98%

Latitude	1975-76			1976-77			Both		
0° - 10°	0.032	0.021	7	0.030	0.014	165	0.030	0.015	172
	0.035	0.056	0.059	0.029	0.042	0.076	0.029	0.044	0.075
10° - 20°	0.021	0.035	88	0.042	0.021	179	0.035	0.028	267
	0.009	0.039	0.106	0.038	0.062	0.099	0.033	0.058	0.102
20° - 30°	0.056	0.040	459	0.062	0.031	429	0.058	0.036	888
	0.043	0.094	0.172	0.057	0.093	0.146	0.049	0.093	0.160
30° - 40°	0.087	0.087	531	0.112	0.098	616	0.100	0.094	1147
	0.060	0.140	0.377	0.083	0.189	0.461	0.074	0.168	0.394
40° - 50°	0.177	0.163	325	0.218	0.138	347	0.198	0.152	672
	0.124	0.356	0.656	0.194	0.351	0.551	0.161	0.353	0.576
50° - 60°	0.289	0.204	197	0.231	0.149	80	0.266	0.191	277
	0.283	0.488	0.734	0.200	0.390	0.580	0.244	0.474	0.708
60° - 70°	-----	-----	0	0.258	0.103	16	0.258	0.103	16
	-----	-----	-----	0.240	0.391	0.442	0.240	0.391	0.442

(b) Spring

Latitude	1975			1976			1977			All		
0° - 10°	0.010	0.011	53	0.032	0.007	46	0.019	0.009	158	0.020	0.012	257
	0.008	0.024	0.040	0.033	0.039	0.055	0.017	0.029	0.046	0.018	0.033	0.048
10° - 20°	0.034	0.026	329	0.052	0.023	207	0.033	0.020	137	0.039	0.025	673
	0.030	0.057	0.089	0.049	0.075	0.109	0.029	0.049	0.103	0.036	0.062	0.107
20° - 30°	0.072	0.039	396	0.091	0.043	669	0.087	0.056	773	0.085	0.049	1838
	0.072	0.114	0.162	0.086	0.134	0.205	0.078	0.137	0.246	0.079	0.132	0.224
30° - 40°	0.179	0.158	382	0.137	0.119	997	0.150	0.152	1008	0.149	0.141	2387
	0.122	0.353	0.634	0.097	0.208	0.550	0.092	0.255	0.679	0.098	0.239	0.620
40° - 50°	0.348	0.217	208	0.272	0.192	749	0.262	0.227	772	0.276	0.213	1729
	0.386	0.609	0.748	0.226	0.485	0.729	0.164	0.532	0.795	0.208	0.518	0.767
50° - 60°	0.323	0.238	117	0.351	0.219	403	0.264	0.205	479	0.316	0.217	999
	0.313	0.583	0.883	0.362	0.561	0.728	0.232	0.488	0.832	0.267	0.578	0.808
60° - 70°	-----	-----	0	0.561	0.130	138	0.467	0.233	38	0.541	0.163	176
	-----	-----	-----	0.575	0.653	0.821	0.525	0.732	0.812	0.569	0.676	0.819
70° - 80°	-----	-----	0	0.488	0.087	26	-----	-----	0	0.488	0.870	26
	-----	-----	-----	0.481	0.581	0.687	-----	-----	-----	0.481	0.581	0.687

[a]Ozone in ppmv.

and 1977; hereinafter designated S75, S76, and S77) and two winter seasons (Dec-Feb 1975-76, and 1976-77; designated W75-76 and W76-77).

The quantity and geographical coverage of the GASP data varies among the seasons as functions of the number of aircraft in service (up to 4) and their routing. Ozone observations are nominally made at 10-minute intervals during flight. GASP data records include location, meteorological data, constituent measurements, and tropopause pressure. All are obtained by the automated systems except for tropopause pressure, which is time-and-space-interpolated from National Meteorological Center (NMC) archived fields (ref. 12). Additional supplemental meteorological parameters, including potential vorticity, geostrophic winds, and static stability were computed for each GASP observation from the NMC isobaric height fields (ref. 20).

GASP ambient ozone concentrations in the Northern Hemisphere between flight levels 335 and 385 (33 500 and 38 500 ft pressure altitude) are summarized in table III by 10° latitude intervals for winter and spring of each year. In addition to the mean, standard deviation, and number of observations, the tabulation includes the median (50th percentile), 84th percentile, and 98th percentile

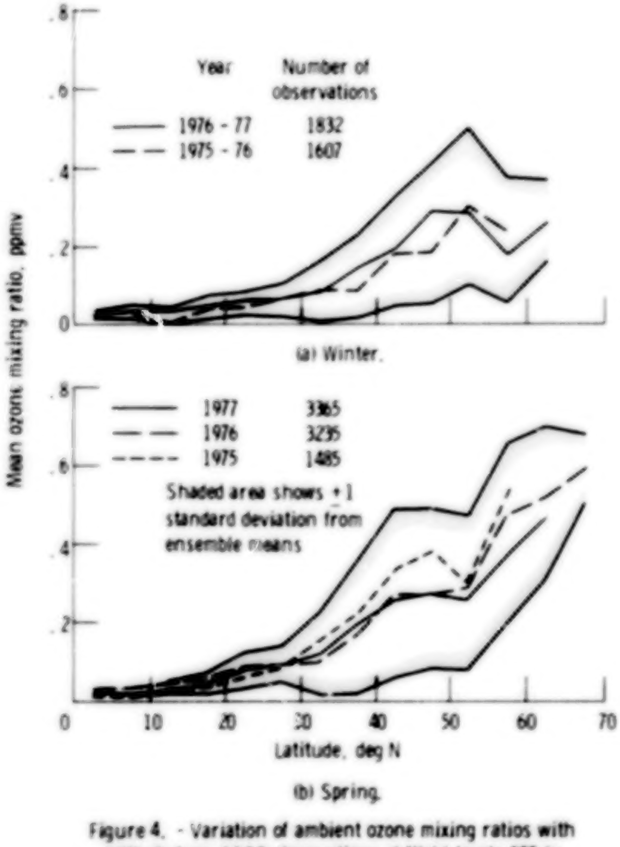


Figure 4. - Variation of ambient ozone mixing ratios with latitude from GASP observations at flight levels 335 to 385 in winter and spring.

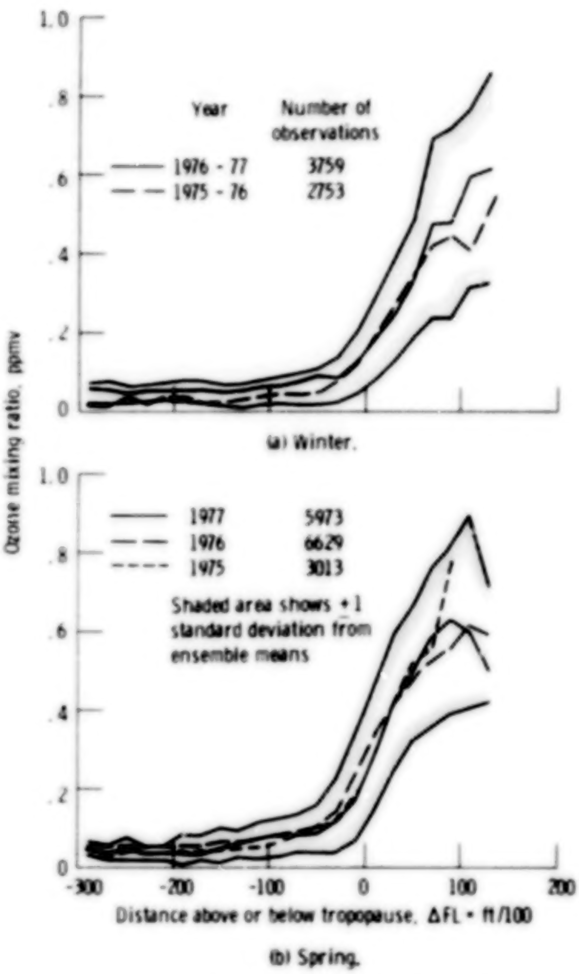


Figure 5. - Distribution of ozone with respect to NMC (Flattery) tropopause from GASP observations.

values. These last three parameters will be discussed in a later section on encounter frequencies.

The latitudinal distribution of the seasonal mean ozone values in this altitude range is shown in figure 4. The corresponding curves for individual months lead to identical conclusions, so for simplicity of presentation we will confine further attention to seasonal distributions. The large natural variability of ozone at these flight levels is indicated by the shaded area which represents ±1 standard deviation from the seasonal ensemble mean for each 5° latitude interval. In comparison with this, the differences among the means for the individual years is small, but since this would be expected from statistical considerations alone, a more careful analysis in regions of apparent differences is warranted. In this regard, bear in mind that because ozone increases rapidly above the tropopause (see fig. 5), above average ozone concentrations at cruise altitudes will result from lower than average tropopause heights, or higher than average ozone levels in the lower stratosphere, or both.

TABLE IV. - INTERANNUAL COMPARISON OF GASP MEAN OZONE LEVELS

AT 0 TO 5000 FEET ABOVE TROPOPAUSE

(a) Winter

Code[a]:			
	Mean	Std. dev.	# Obs.
	$\overline{\Delta P}$	$\overline{T}$	$\overline{FL}$

Latitude	1975-76			1976-77			Both		
20° - 30°	0.131	0.063	32	0.171	0.070	19	0.146	0.068	51
	18	-50	377	16	-57	406	17	-53	388
30° - 40°	0.204	0.102	168	0.216	0.126	315	0.212	0.119	483
	21	-52	379	21	-56	390	21	-54	386
40° - 50°	0.243	0.122	235	0.241	0.136	316	0.242	0.130	551
	24	-55	373	28	-55	372	26	-55	372
50° - 60°	0.363	0.152	101	0.264	0.131	50	0.330	0.153	151
	28	-55	357	38	-53	358	31	-54	358
60° - 70°	0.217	0.121	6	0.250	0.067	9	0.236	0.094	15
	25	-56	331	28	-52	364	27	-54	351
All	0.246	0.135	542	0.230	0.131	709	0.237	0.133	1251
	23	-54	372	25	-56	380	24	-55	376

(b) Spring

Latitude	1975			1976			1977			All		
[illegible] - 30°	0.160	0.007	2	0.089	0.003	5	0.187	0.052	28	0.172	0.058	35
	2	-55	371	3	-56	390	7	-64	410	6	-62	405
30° - 40°	0.362	0.194	158	0.3[illegible]	0.147	285	0.351	0.200	332	0.341	0.182	775
	24	-55	378	23	-55	388	19	-58	396	21	-56	389
40° - 50°	0.415	0.180	237	0.372	0.165	635	0.391	0.201	488	0.386	0.182	1360
	31	-54	374	24	-54	380	25	-54	380	26	-54	379
50° - 60°	0.362	0.194	103	0.437	0.136	269	0.360	0.198	342	0.389	0.181	714
	26	-54	350	24	-54	372	26	-52	369	25	-53	367
60° - 70°	0.261	-----	1	0.498	0.122	109	0.507	0.274	20	0.498	0.[illegible]56	130
	7	-45	290	27	-53	361	33	-51	358	28	-53	360
70° - 80°	-----	-----	0	0.441	0.066	11	-----	-----	0	0.441	0.066	11
	-----	-----	-----	26	-59	350	-----	-----	-----	26	-59	350
All	0.386	0.189	501	0.383	0.161	1314	0.369	0.203	1210	0.378	0.183	3025
	28	-54	370	24	-54	378	23	-55	382	24	-54	378

[a]Ozone in ppmv.

$\overline{\Delta P}$ is the mean pressure interval from tropopause.

$\overline{T}$ is the mean ambient (static) temperature.

$\overline{FL}$ is the mean flight level.

TABLE V. - INTERANNUAL COMPARISON OF GASP MEAN OZONE LEVELS

AT 5000 TO 10 000 FEET ABOVE TROPOPAUSE

(a) Winter

Code[a]:

Mean	Std. dev.	# Obs.
$\overline{\Delta P}$	$\overline{T}$	$\overline{FL}$

Latitude	1975-76			1976-77			Both		
30° - 40°	0.252	0.179	15	0.371	0.211	107	0.358	0.211	122
	77	-43	370	70	-52	416	71	-51	411
40° - 50°	0.416	0.149	56	0.407	0.227	153	0.409	0.209	209
	83	-50	389	78	-50	398	79	-50	395
50° - 60°	0.444	0.130	43	0.542	0.256	138	0.518	0.236	181
	79	-51	357	78	-51	401	78	-51	390
60° - 70°	-----	-----	0	0.442	0.137	52	0.442	0.137	52
	-----	-----	-----	81	-49	390	81	-49	390
All	0.406	0.157	114	0.444	0.235	450	0.436	0.222	564
	81	-49	374	76	-51	402	77	-50	397

(b) Spring

Latitude	1975			1976			1977			All		
30° - 40°	0.593	0.200	24	0.418	0.165	61	0.585	0.220	71	0.521	0.213	156
	71	-51	395	73	-48	402	70	-50	399	71	-49	400
40° - 50°	0.578	0.217	105	0.497	0.175	273	0.580	0.230	179	0.539	0.206	557
	68	-49	391	72	-49	408	72	-48	398	71	-49	402
50° - 60°	0.521	0.206	24	0.575	0.166	148	0.567	0.195	236	0.567	0.186	408
	83	-46	368	83	-46	382	77	-46	390	80	-46	386
60° - 70°	0.550	0.058	13	0.632	0.104	51	0.500	0.264	17	0.591	0.158	81
	96	-43	329	78	-48	372	82	-44	372	82	-46	366
70° - 80°	-----	-----	0	0.629	0.056	5	-----	-----	0	0.629	0.056	5
	-----	-----	-----	70	-43	351	-----	-----	-----	70	-43	351
All	0.570	0.206	166	0.523	0.175	538	0.572	0.214	503	0.550	0.198	1207
	73	-49	383	76	-48	396	74	-47	393	75	-48	393

[a]Ozone in ppmv.

$\overline{\Delta P}$ is the mean pressure interval from tropopause.

$\overline{T}$ is the mean ambient (static) temperature.

$\overline{FL}$ is the mean flight level.

Note specifically in figure 4 for latitudes from 35° to 50° N that the mean of all ambient ozone observations made by GASP airliners was higher in the winter of 1976-77 than in the winter of 1975-76, and higher in the spring of 1975 than in the corresponding period of either 1976 or 1977. To examine these apparent anomalies further, consider first the distribution of ozone with respect to distance from the tropopause for each year and season in figure 5. From this and from tables IV and V, which

give mean ozone levels and standard deviations for 0 to 5000 feet and 5000 to 10 000 feet intervals, respectively, above the tropopause, we conclude that there were no significant interannual differences in the distribution of zonal mean ozone with respect to the tropopause in either season.

Proceeding, figure 6 shows the winter and spring Northern Hemisphere zonal mean tropopause pressures from NMC archived fields[2,3]. For all latitudes poleward of 35° N, the tropopause pressure levels are nearly equal each season, and we conclude that the tropopause pressures were not anomalous in 1976-77.

Having concluded that neither the zonal mean tropopause location, nor the distribution of ozone with respect to the tropopause were anomalous in any of the seasons examined, we are led to hypothesize that the differences in mean ozone levels in figure 4 are the result of longitudinal or synoptic biasing in the GASP data sample (i.e., the GASP means do not always represent zonal mean conditions).

To investigate this hypothesis, consider the mean tropopause pressures from the GASP data sample shown in figure 7. First, the winter curves in this figure clearly show that poleward of 35° N, the tropopause level from the GASP records in 1975-76 is higher than for the 1976-77 sample. Comparing these curves with the corresponding ones in figure 6, it is apparent that the W76-77 GASP mean tropopause pressure curve is in good agreement with the zonal mean tropopause pressure but that poleward of 35° N, the W75-76 GASP mean tropopause is high. From this, and the relation between ozone and distance from the tropopause, it follows that the W76-77 GASP ozone means are average but that the W75-76 GASP ozone means are low.

A completely parallel argument regarding the spring mean tropopause and ozone levels leads to the conclusion that the 1976 and 1977 GASP mean ozone levels are representative of zonal means in average years, but that the spring 1975 GASP mean ozone

[2]Note that the tropopause pressures shown for S75, W76-77, and S77 were determined by the Flattery global analysis method, whereas NMC tropopause pressures for W75-76 and S76 were obtained using the Gustafson method, and that, in ref. 12, it was reported that the schemes appeared to define different tropopause locations. We have therefore reduced all NMC tropopause pressures for W75-76 and S76 by 50 hPa based on (unpublished) analyses of GASP data from July 1976 through September 1977 for which tropopause pressure values from both schemes were available.

[3]Tropopause pressures for 0 to 30° N from the NMC 65 by 65 grid are known to be too high (i.e., S75, W75-76, S76, here) but since GASP observations are below the indicated tropopause in this region, the error in distance from the tropopause is of minimal consequence in our analysis.

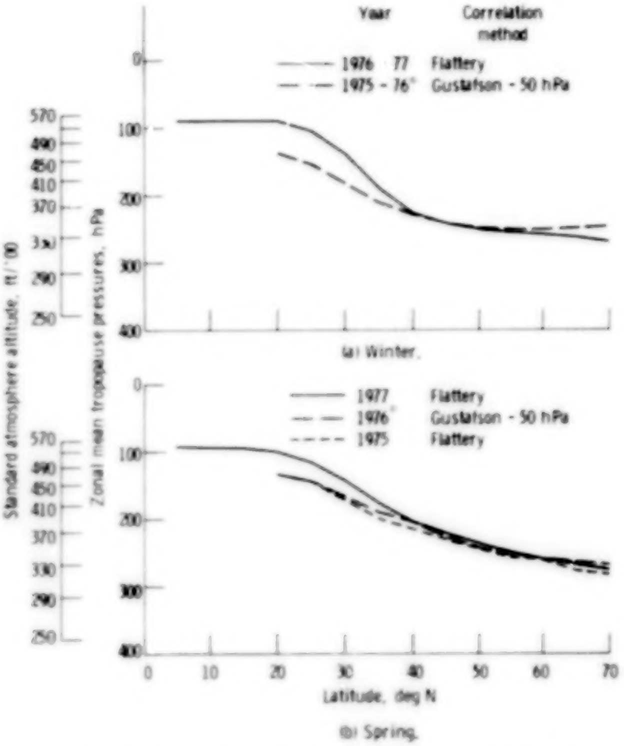


Figure 6. - Variation of zonal mean National Meteorological Center tropopause pressures with latitude. (*See footnote 2.)

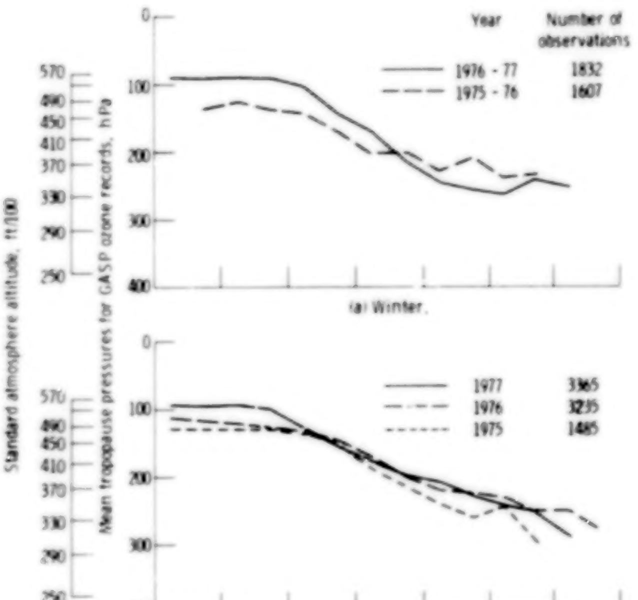


Figure 7. - Mean tropopause pressures from GASP ozone data records at flight levels 335 to 385 (corresponding ozone levels are shown in fig. 4).

values are high because the mean tropopause heights from the GASP sample points are lower than the zonal mean levels.

As pointed out in the Introduction and as is apparent in the previous analyses, mean ozone levels vary significantly with season, altitude, and latitude. In addition, however, because of longitudinal mean meteorological differences in the strength of synoptic scale weather systems, one cannot overlook the possibility of significant longitudinal mean ozone differences. Consider, for example, the mean ozone levels from GASP observations in the Pacific (75° W – 180° – 105° E) and Atlantic (105° E – 0 – 75° W) hemispheres at flight levels 335 to 385 in the winter and spring of 1976-77 (fig. 8).

In the winter no comparison is possible poleward of 50° N, as GASP obtained no data over the Atlantic at these latitudes; however, mean ozone levels in the Atlantic and Pacific Hemispheres are virtually the same from 35° to 50° N latitude. In the spring mean ozone levels for the Pacific hemisphere were from 80 to 150 percent greater than the corresponding values in the Atlantic hemisphere for latitudes poleward of 45° N. Note, however, in figure 9 that the interhemispheric differences are about the same in the S75 and S76 mean values and that in figure 10 ozone levels over the North Pacific in S75 and S76 were greater than those observed in S77.

Thus, again no interannual ozone anomalies were detected, but there is a statistically significant (at the 95th percent level) and apparently normal ozone difference between the Atlantic and Pacific

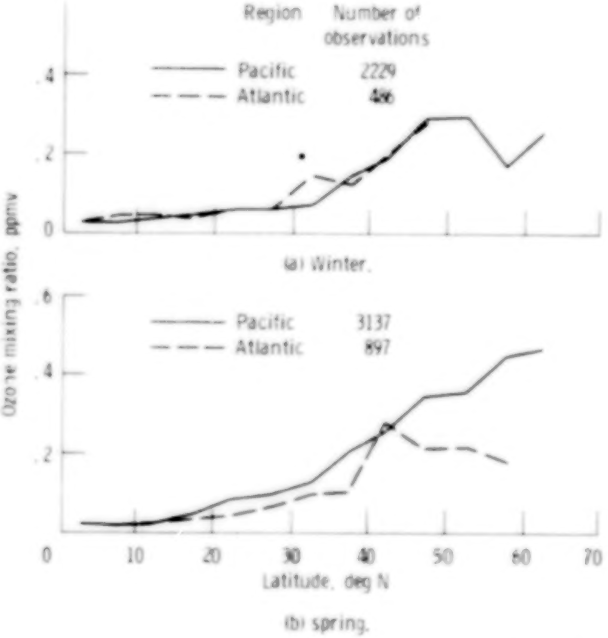


Figure 8. - Latitudinal ozone distributions from GASP observations for Atlantic (105° E to 75° W) and Pacific (75° W to 105° E) hemispheres in winter and spring 1976-77 at flight levels 335 to 385.

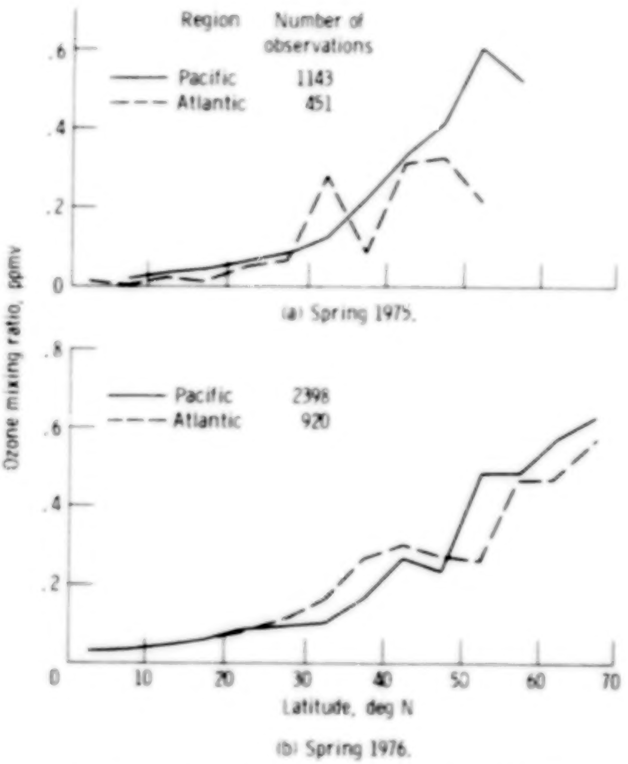


Figure 9. - Latitudinal ozone distributions from GASP observations for Atlantic (105° E to 75° W) and Pacific (75° W to 105° E) hemispheres in spring at flight levels 335 to 385.

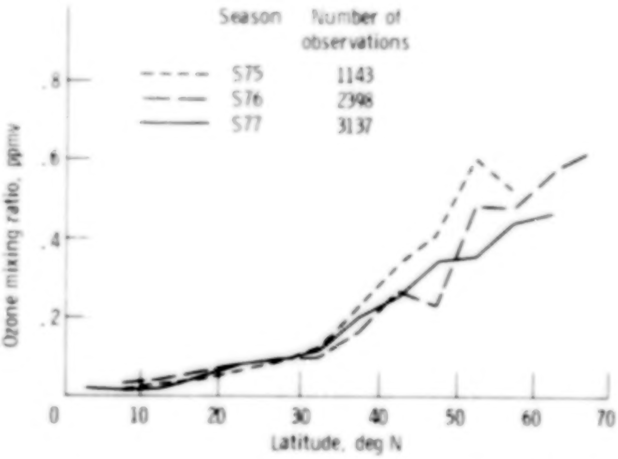
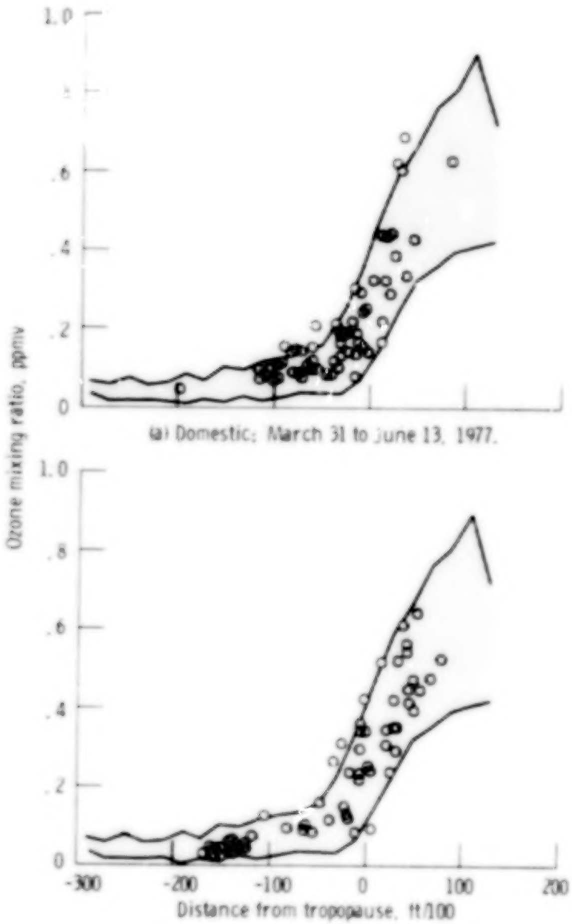


Figure 10. - Latitudinal ozone distributions from GASP observations for Pacific (75° W to 105° E) hemisphere in spring at flight levels 335 to 385.



(a) Domestic; March 31 to June 13, 1977.

(b) International; April 26 to May 31, 1977.

Figure 11. - Flight-mean ambient ozone as function of flight-mean distance from tropopause for 134 spring 1977 GASP flights. Shaded area shows ±1 standard deviation from 1975-77 ensemble spring mean.

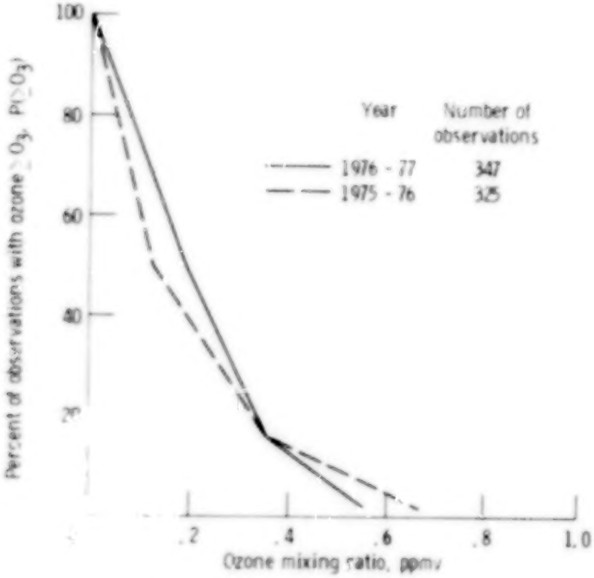


Figure 12. - Cumulative frequency distributions from GASP data (table III) for winter; 40° to 50° N latitude; flight levels 335 to 385.

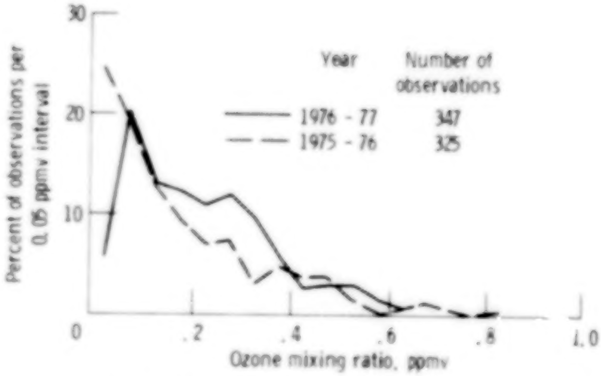


Figure 13. - Ozone frequency distributions from GASP data for winter; 40° to 50° N latitude; flight levels 335 to 385.

hemispheres at latitudes poleward of 45° N in the spring. This is probably because of the strong quasipermanent trough (relative minimum in the height of a constant pressure surface) over the Aleutians and North Pacific and the inverse relationship between pressure-height and ozone level.

Finally, it is interesting to compare individual flight averages with the ensemble results shown above. Thus, in figure 11 average ozone levels for 134 GASP flights in spring 1977 (refs. 12 and 13) are plotted against the mean distance from the tropopause during each flight. Averages from flights in the contiguous U.S. and to Hawaii are shown in part (a), and averages from international flights are shown in part (b). The shaded background is ±1 standard deviation from the ensemble mean for all GASP spring data 1975-77. It is apparent here that the variability among individual flights is of the same order of magnitude as that of the ensemble.

Encounter Frequencies

Since winter-spring 1976-77 was average with respect to mean ozone levels at commercial airplane cruise altitudes, we would expect that high ambient ozone levels were encountered by the world aircraft fleet at an average frequency, excluding of course any differences attributable to changes in routing or flight levels during 1977. The completeness of the GASP data permits analysis of encounter frequencies directly; however, one must not assume a priori that results from four B747's are representative of conditions encountered by all aircraft.

In addition to the means and standard deviations discussed previously, table III include median (50th percentile), 84th percentile, and 98th percentile values for each latitude interval, year, and season. Although methods for estimating encounter frequencies from mean and standard deviation data have been shown to give reasonable estimates (ref. 21), it is of course better to use empirical probability data directly when they are available.

Referring to table III, for winter and 40° to 50° N, we find that the mean and median values were smaller in W75-76 than in W76-77, which is consistent with the higher GASP mean tropopause for W75-76, but that the 84th percentile values for the two winters were nearly equal. The cumulative frequency distributions[4], plotted in figure 12 from table III data, show this and suggest that a broader range, and higher peak ozone concentrations were encountered in W75-76 than in W76-77. This is confirmed by the complete empirical frequency distributions in figure 13, which show that, although ozone levels from 0.15 to 0.35 ppmv (typical of the first 5000 feet above the tropopause) were encountered more frequently in W76-77, both very low and very high ozone levels were encountered more frequently in W75-76.

As a second example, consider the same latitude interval, 40° to 50° N, in the spring. The cumulative frequency distributions, plotted from table III, are shown in figure 14. Clearly, high ambient ozone levels were encountered much more frequently in S75 than in either S76 or S77, as would be expected since the low altitude of the GASP-sample tropopause in S75 resulted in a larger than normal percentage of observations in the stratosphere (74 percent for S75 compared with 40 percent for S76 and S77).

Recall that in the preceding mean value analyses, ozone levels were higher over the North Pacific than over the North Atlantic. If we select 45° to 55° N as a representative interval with a statistically significant difference in mean levels between the Atlantic and Pacific hemispheres, we see in figure 15 that, for any given year, the probability of encountering a specified ozone level is indeed higher in the Pacific hemisphere than in the Atlantic. Note also, in part (d) of this figure, that the encounter frequency distributions for the Pacific hemisphere are comparable in S77 and S76, but that all ozone levels greater than 0.1 ppmv were encountered more frequently in S75 than in either S76 or S77.

Thus, although there is again no evidence that anomalously high ozone levels were present in the winter and spring of 1976-77, the GASP zonal mean, Altantic hemisphere, and Pacific hemisphere

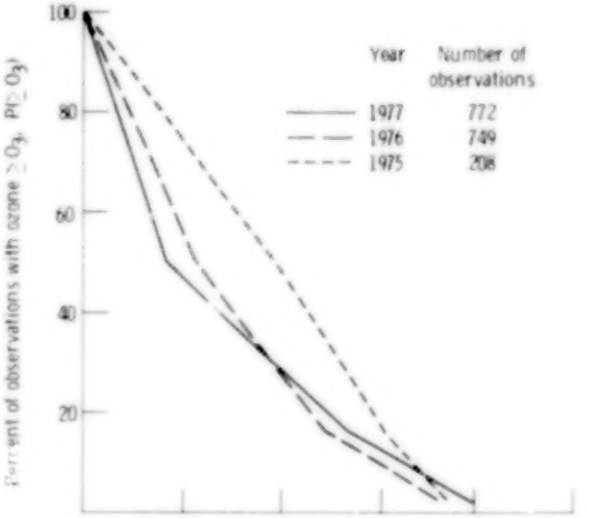


Figure 14. - Cumulative ozone frequency distributions from GASP data (table III) for spring; 40° to 50° N latitude; flight levels 335 to 385.

[4] These curves show the percent of observations (on the ordinate) in which the ozone level equalled or exceeded any given ozone level (on the abscissa).

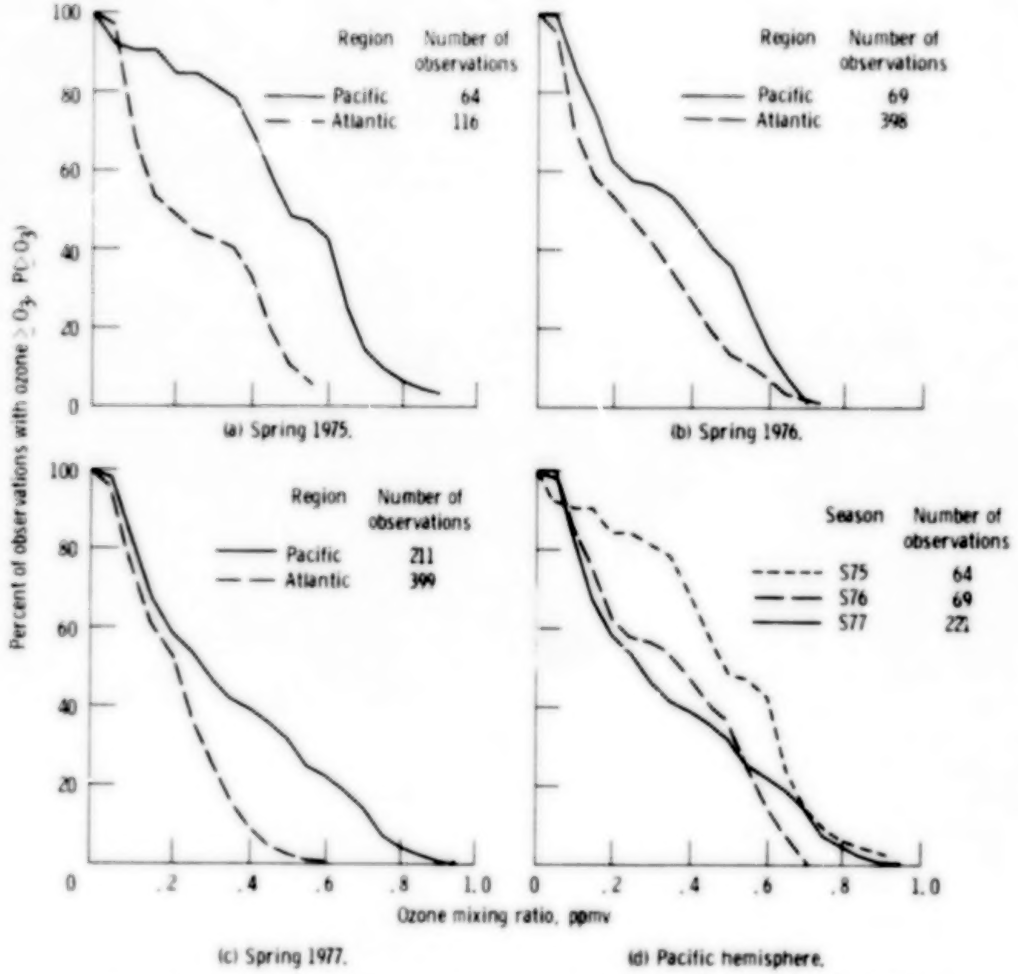


Figure 15. - Cumulative ozone frequency distributions from GASP data for spring; 45° to 55° N latitude; flight levels 395 to 385. Atlantic hemisphere, 105° E to 75° W longitude; Pacific hemisphere, 75° W to 105° E longitude.

encounter frequencies for the different years show considerable variability. This suggests that the observed differences are representative of the range of ambient ozone encounter frequencies to be expected among flights along the same route in average years.

Conclusions

1. Ozonesonde data for 13 years at eight stations over North America and Europe indicate that ozone levels (mixing ratio) near airline cruise altitudes were near average during winter and spring, of 1976-77

2. Available aircraft ozone measurements from GASP for 3 years (1975-77) indicate the following:

a. Zonal mean ozone levels were average during the 1976-77 ozone season.

b. There is a statistically significant and apparently usual ozone difference between the Atlantic and Pacific hemispheres at latitudes poleward of 45° north in the spring, with the Pacific being higher.

c. Encounter frequencies follow the mean levels and trends, but considerable variability must be expected among flights on the same route.

3. The available data give no basis for claiming that ozone at aircraft operating levels was anomalously high in either winter or spring of 1976-77.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, August, 28, 1980

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16. Abstract

It has been speculated that the ozone sickness experienced by some airline passengers and crew members during the winter and spring of 1976-77 were induced by abnormally high concentrations of ambient atmospheric ozone. To investigate the possibility that 1976-77 was anomalous, ozone measurements from balloons for up to 13 years and from Global Atmospheric Sampling Program (GASP) equipped aircraft for 3 years have been studied. The analyses presented herein show that the winter and spring seasons of 1976-77 were averaged statistically, and no evidence was found to suggest that there was more than a usual variation in the frequency that commercial airplanes encountered high ambient ozone concentrations.

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